COMBINING MONOLITHIC AND REPACKED SOIL TANKS FOR LYSIMETERS FROM HIGH WATER TABLE SITES

A. D. Schneider, J. E. Ayars, C. J. Phene

ABSTRACT. *Two soil monoliths collected above the water table and two tanks repacked with soil from below the water table were combined for weighing lysimeters to be used in soil salinity research. Deadweights were used to press two 2 × 4-m (6.56 × 13.1-ft) surface area × 1.68-m (5.50-ft) deep tanks into the soil, and the enclosed monoliths were undercut with steel plates. Innovative equipment was used to control the deadweight movement, to maintain straight side walls on the monolith tanks and to place the undercutting plates beneath the soil tanks. The monoliths and the soil for repacking the 1.07-m (3.50-ft) deep lower tanks were trucked 80 km (50 mi) to a research location where the monolithic and repacked soil tanks were joined and placed on weighing lysimeter scales. The monolithic/repacked soil tanks are expected to provide the advantages of a monolithic lysimeter without the disadvantage of collecting a 3.0-m (9.84-ft) deep monolith at a high water table site.* ***Keywords.*** *Monolith, Lysimeter, Repacked, Salinity, Water table.*

The irrigated lands along the west side of the San Joaquin Valley in California are subject to high water tables and severe salinity problems (San Joaquin Valley Drainage Program, 1990). The USDA Agricultural Research Service (ARS) is cooperating with California State Agencies to developing management guidelines for these difficult-to-manage soils. The goal of this cooperative research is to measure soil water hydraulic parameters, calibrate crop water use and salt transport models and evaluate irrigation management scenarios. The primary research tools used to collecting data for calibrating models and evaluating irrigation scenarios are two weighing lysimeters.

Obtaining reliable weighing lysimeter data required monolithic soil tanks to preserve soil hydraulic properties and salinity profiles (Marek et al., 1988; Schneider and Howell, 1991). The monolithic soil tanks needed to be sufficiently deep to allow the water table to fluctuate between the 1.0 and 2.5-m (3.28 and 8.20-ft) depths. The tank surface area needed to be sufficiently large to allow accurate measurement of both evapotranspiration and crop yields. Collecting deep soil monoliths was complicated by a high water table that is seldom more than 1.75 m (5.74 ft) below the ground surface.

Literature on lysimeters in which monolithic and repacked soil tanks were combined is limited. Gee (1987) placed a soil monolith over a shallow lower tank containing only drainage tubes and a sand filter. The soil monolith was obtained by pressing down a bottomless steel tank and then undercutting it with a solid steel plate (Gee et al., 1991; Kirkham et al., 1984). Mukammal et al. (1971) placed 65 × 65 × 78-cm (26 × 26 × 31-in.) deep monolithic blocks of soil inside a 6.1-m (20-ft) diameter soil tank, but the monolith tank was not combined with a lower soil tank.

The purpose of this article is to describe equipment and procedures used for collecting soil monoliths in steel tanks, repacking lower soil tanks and joining the monolithic and repacked tanks into a single soil tank for weighing lysimeters. The monolithic/repacked soil tanks are expected to provide the advantages of a monolithic lysimeter without the disadvantages of collecting a single (9.84-ft) deep monolith. Lowering the high water table for collection of a deep monolith would have been a time consuming operation requiring several wells into the slowly permeable clay. In addition, collection of a deep monolith is much more difficult than collecting the 1.68-m (5-ft) deep one described here. Transporting the deep monolith to the lysimeter site would have required a larger crane and heavier duty trucks with special weight permits.

EQUIPMENT DESIGN

To meet the unique research requirements we collected two soil monoliths that were joined to two repacked, lower soil tanks and located the lysimeters approximately 80 km (50 mi) from the high water table site. The monolith collection site, located 13 km (8 mi) south of Mendota, California, and 3 km (2 mi) east of State Highway 33, is near the natural drainage way of the South San Joaquin Valley. The unclassified soil is a uniform clay with a high salt content. After the monoliths were collected they were trucked to the lysimeter site at the ARS research location at Parlier, California. Saturated soil, excavated from beneath the monolith collection site, was also transported to Parlier, California, where it was used to fill repacked soil tanks with the same surface area as the monolith tanks. The

Article has been reviewed and approved for publication by the Soil and Water Div. of ASAE.

Contribution from USDA Agricultural Research Service, Pacific West Area, Water Management Research Laboratory, Fresno, Calif., and Southern Plains Area, Conservation and Production Research Laboratory, Bushland, Tex. The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation or exclusion by the USDA-Agricultural Research Service.

The authors are **Arland D. Schneider, *ASAE Member Engineer,*** Agricultural Engineer, USDA-ARS, Bushland, Tex.; **James E. Ayars, *ASAE Member Engineer,*** Agricultural Engineer, and **Claude J. Phene, *ASAE Member Engineer,*** Supervisory Soil Scientist (former), USDA-ARS, Fresno, Calif. **Corresponding author:** Arland D. Schneider, USDA-ARS, P.O. Drawer 10, Bushland, TX 79012; telephone: (806) 356-5732; e-mail: <aschneid@ag.gov>.

upper monolithic and lower repacked soil tanks were joined together, and the combined tanks were placed on the lysimeter scales. The 45-Mg (100,000-lb) mechanical floor scales were manufactured by Cardinal Scale Manufacturing Co. with a mechanical advantage of 1413. Counterweights offset sufficient dead weight of the soil and tank to allow the use of a 22.7-kg (50-lb) Alphatron load cell. All equipment was specifically designed to minimize hand labor by utilizing large hoisting equipment and power tools. Since the lysimeters are not located at the monolith collection site, soil compaction or other disturbances at the collection site were not critical.

The traditional monolith collection process of pressing down a bottomless steel tank and then undercutting the enclosed monolith was utilized (Schneider and Howell, 1991). Deadweights were used to press down the steel tanks because the saturated soil did not have sufficient strength to support high capacity anchors for the hydraulic pulldown procedure (Schneider et al., 1988). The enclosed monoliths were undercut with solid steel plates so that the bottom of the monoliths were totally enclosed during hauling. The lower tanks were filled by packing the desired mass of soil in 0.15-m (6-in.) depth increments and then saturating and draining the repacked soil.

We selected 9.5-mm (3/8-in.) steel soil tanks for this project. Walls this thick provided sufficient strength during the monolith collection process; yet, they were thin enough to use in the completed lysimeters. The soil tanks and monolith collection equipment were of ASTM A36 structural steel unless otherwise noted and were designed and fabricated by ARS personnel. Detailed drawings of the soil tanks and monolith collection equipment may be obtained from the USDA-ARS, Water Management Research Laboratory (2021 S. Peach Ave., Fresno, CA 93727).

Soil Tanks

Both the monolithic and repacked soil tanks had 2 × 4-m (6.56 × 13.1-ft) surface areas and were reinforced with 100 × 50 × 6.4-mm (4 × 2 × 1/4-in.) rectangular tubing (fig. 1). The bottom edges of the 1.68-m (5.50-ft) deep monolithic tanks were beveled 45° to the inside to form a cutting edge. The 1.07-m (3.50-ft) deep lower tanks, constructed similar to the upper tanks, had two rings of reinforcing tubing and 15.9-mm (5/8-in.) thick bottoms. A 1414-mm (4.64-ft) wide × 2828-mm (9.28-ft) long × 610-mm (2-ft) high rectangular wall of 6-mm (1/4-in.) thick steel was welded to the center of each tank bottom (Marek et al., 1988). This wall underlies half the surface area of the lysimeter and divides the drainage water from the inner and outer halves of the soil tank.

The monolithic soil tanks had several features to facilitate collecting and lifting the monoliths. Two lifting bars were attached to each 4-m (13.2-ft) long wall of the tanks to facilitate lifting the monoliths and later lifting the combined tanks onto the lysimeter scales (fig. 1). The walls were reinforced at the bottom with heavy steel angles to reduce warping. These reinforcing angles extended beyond each end of the tanks so that lowering hoists could be attached to the tanks. Pipe columns with 22.2-mm (7/8-in.) adjusting bolts on top were placed around the monolith tanks. Deadweight was transferred directly through these columns and the reinforcing angles to the cutting edges.

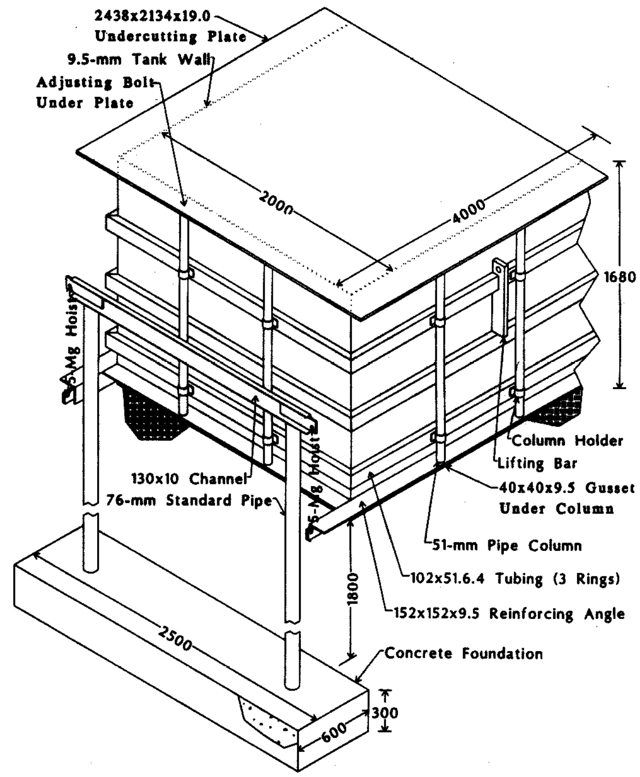

Figure 1–Isometric view of half a monolith tank and the equipment for pressing down the monolith. All dimensions are in millimeters.

The transferred weight placed a moment on the reinforcing angles and rotated the bottom of walls inward. These actions reduced the forces that tended to deform the monolith tank and bulge the walls outward.

Deadweights

For deadweights, we used the heavy steel plates to be used to undercut the monoliths and the lower soil tanks which were filled with water. The four steel undercutting plates were 19.1 mm (3/4 in.) thick and each weighed 0.780 Mg (1,720 lb). The two lower soil tanks each weighed 2.13 Mg (4,700 lb) and could be filled with an additional 8.53 Mg (18,800 lb) of water. Total deadweight available with this equipment was 24.44 Mg (53,880 lb).

Lowering Equipment

To maintain alignment of the monolith tanks and vertical control of the deadweights we utilized lowering equipment at each end of the monolith tanks (fig. 1). A 10-Mg (11-ton) capacity steel frame was set in a temporary concrete foundation at each end of the tank. At each corner of the tank, a 5-Mg (5.5-ton) capacity chain hoist was suspended from one end of a frame and attached to the heavy angle extending from the monolith tank. The four hoists were released simultaneously to provide safe, controlled downward movement of the monolith tanks and deadweights.

Undercutting Equipment

The three main components of the monolith undercutting equipment were the undercutting plates, the jacking equipment and the guide frames (fig. 2). The monolith was undercut with two plates, one from each end,

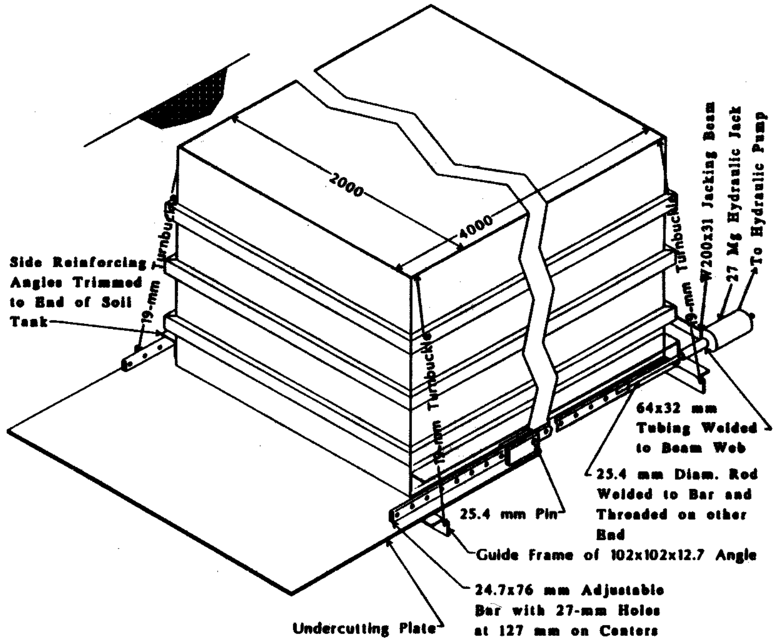

Figure 2–Isometeric view of the equipment for undercutting a monolith. All dimensions are in millimeters.

to reduce the maximum undercutting force. We selected 19.1-mm (3/4-in.) thick plates since a 12.7-mm (1/2-in.) thick plate was used satisfactorily by Kirkham et al. (1984) to undercut a 1.52 × 1.52-m (5 × 5-ft) surface area monolith. The leading edge of the undercutting plates was beveled at a 45° angle to the top, and a 3 × 25-mm (1/8 × 1 in.) bar was welded along the lower edge to reduce friction on the sliding plate. The guide frames were fabricated of angle with the vertical legs of the angles directly below the tank walls. They were vertically positioned with 19-mm (3/4-in.) turnbuckles that were suspended from the tank walls.

The jacking equipment consisted of two, single-acting, hollow-cylinder hydraulic jacks, adjustable bars on each side of the monolith tank, and a jacking beam opposite the undercutting plate (fig. 2). Simplex Model RC306 hydraulic jacks with a 27-Mg (30-ton) capacity were powered by an Enerpac Model PEM 2022 electric-powered hydraulic pump. The pump operated on 120 Vac and provided 11.5 mL/s (42 in.^{3}/min) of hydraulic oil at a maximum pressure of 69 MPa (10,000 psi). The adjustable bar was pinned to the undercutting plate at one end and had a threaded 25.4-mm (1-in.) rod of AISI 4140 steel at the other end (fig. 2).

Procedure

Monolith Collection

Site Preparation. Site preparation consisted of installing the lowering frames and positioning the monolith tanks, hoists and deadweights. To install the lowering frames, we excavated a 0.6-m wide trench at each end of the monolith tank with a backhoe, suspended the lowering frames at the correct elevation and placed high-early-strength concrete around the bottom of the frames. The monolith tanks and deadweights were lifted into place with a 27-Mg (30-ton) capacity hydraulic crane. Figure 3 illustrates a tank and equipment in place and ready to begin the pressdown operation.

Pressing Down Monolith Tanks. Pressing down a monolith tank was a repeated sequence of lowering a tank and then excavating around the tank. First, we lowered a tank with the chain hoists until the reinforcing angles rested on the soil. Then, we excavated along the outside of the 4-m (13.2-ft) long walls to about 0.3 m (1 ft) below the cutting edge with a backhoe. As the monolith tank was lowered further, the soil directly beneath the reinforcing angles was removed with shovels and hoes. Initially, the soil trimmed by the 2-m (6.56-ft) long walls of the tank fell into the trenches for the lowering frames, but as the tank was pressed deeper, this soil had to be shoveled into the

See Figure 3 at end of document

Figure 3–Monolith tank with all equipment and deadweights in place and pressed down about 0.3 m.

backhoe trench. We were careful to leave about 150 mm (6 in.) of undisturbed soil between the tank wall and the trench. Having undisturbed soil on both sides of the cutting edge reduced the tendency of the walls to bulge outward. Both monolith tanks were lowered about 1 m (3.2 ft) with the 7.38-Mg (16,300-lb) deadweight of the four undercutting plates and two lower soil tanks. We filled the lower of the two soil tanks with water, and were able to press down both monolith tanks with 15.9 Mg (35,000 lb) of mass or less. Releasing the ratchet type chain hoists uniformly, allowed us to continuously maintain the tanks in a level position using carpenter levels. With this control there was no danger of the water shifting in the tanks. With five workers we pressed down a monolith in six hours.

The loading on the pipe columns was continuously increased as the monolith tanks were pressed down. Initially, a small fraction of the load was lifted with the adjusting bolts at the top of the columns. As the pressdown depth increased, we increased the loading on the columns until they columns supported essentially all of the deadweight. As water was added to the tanks, the adjusting bolts were further extended to compensate for any bending in the reinforcing angles and the plates directly above the monolith tank.

Undercutting Monoliths. Before positioning the undercutting equipment, the water in the lower tank was drained back into a water trailer, and the weights and lowering frames were removed with the crane. The pipe columns and end reinforcing angles were removed from the monolith tank, and the extensions and gussets on the side reinforcing angles were cut off with an acetylene torch. Then, we excavated at both ends of the monolith tank to provide room for the undercutting plates.

Positioning of the undercutting equipment began with the installation of the guide frame which was bolted together beneath the monolith tank and supported with the turnbuckles (fig. 2). Then, an undercutting plate was positioned with the cutting edge on the guide frame, and the trailing edge supported by a hand hydraulic jack. The front edge of the undercutting plate was pulled snugly against the bottom of the monolith tank with the turnbuckles. The guide frame thus insured that the plate would cut directly beneath the tank. The jacking beam, adjustable bar and hydraulic jacks were then positioned, and the hoses of the hydraulic pump were attached to the jacks.

The undercutting procedure was a repetition of pulling the plate about 125-mm (5-in.) with the hydraulic jacks and then collapsing the hydraulic jacks and repinning the adjustable bar for the next cut (fig. 4). Individual valves on the hydraulic lines allowed us to control the rate of either jack and thus keep the plates aligned with the tanks. The jacks did not have spring retracting cylinders so we used 1-Mg (1-ton) hoists to collapse the jacks and position the adjustable bars for repinning. Jacking one undercutting plate under half of a monolith tank took a crew of 5 workers about 1 h. After jacking in the first plate, we reversed the jacking equipment and jacked in the second plate from the opposite side.

Transporting Monoliths

A 91-Mg (100-ton) capacity crane (fig. 5) was used to lift the monoliths onto drop-bed tractor-trailers for hauling. The tractor and trailer each had eight load wheels. We attached each undercutting plate to the first monolith tank with four, 8-mm (5/16-in.) link chains tensioned with load binders. This monolith slipped down inside the tank about 25 mm (1 in.), but the second monolith with six chains on each plate had essentially no slippage. There was no visible bending of the four plates supporting the two monoliths. The load indicator in the crane indicated weights of 25.4 and 25.9 Mg (56,000 and 57,000 lb) for the two monoliths as shown in figure 5. At Parlier, the monoliths and bottom tanks were positioned so that they could be readily joined after repacking the lower tanks with soil.

Repacking Lower Tanks

Soil, excavated at the monolith collection site, was hauled to Parlier and stored under plastic tarpaulins while the bottom tanks were prepared for instrumentation. The

See Figure 4 at end of document

Figure 4–An undercutting plate being jacked under one of the soil monoliths.

See Figure 5 at end of document

Figure 5–A soil monolith being lifted from the ground to be loaded onto a truck.

tarpaulins prevented leaching of salts by rainfall during the winter months. Prior to packing the tanks, the soil water content was gravimetrically measured for each soil pile. The mass of soil required for 0.15-m (6-in.) depth increments was calculated based on the gravimetric water content and the original bulk density. The inside of the tank was marked in corresponding 0.15-m (6-in.) depth increments. The two lower 0.15-m (6-in.) depth increments were filled with washed sand to cover drainage tubes. Then, soil was weighed in a 113-L (30-gal) metal trash can and lifted into the soil tank with a backhoe. The soil was spread with a rake and tamped with a 30-cm^2 (4.6-in.^{2}) tamper as needed to place the required weight of soil within each 0.15-m (6-in.) increment. The time required to repack one lower tank was approximately 90 man-hours.

Joining Soil Tanks

The soil tanks were combined by carefully positioning the monolithic tank over the repacked tank with a 91-Mg (100-ton) capacity crane (fig. 6) and then later joining the two tanks by welding. Accurately positioning a heavy load with a crane is difficult, so we built frames to align the upper and lower tanks. Each undercutting plate was attached to the monolith tank with seven 8-mm (5/16-in.) chains, the monolith was lifted and positioned over the lower tank and the alignment frames were connected to both tanks. When the tanks were satisfactorily aligned, we lowered the monolith tank onto the lower tank.

Removal of the undercutting plates proved to be the most difficult part of the tank joining operation. To simultaneously pull out the two plates from under a monolith, we rented two heavy-duty winch trucks with each having a single-line winch capacity of 133 kN (30,000 lb) or greater. With double lines, the winches had sufficient pulling capacity to pull the undercutting plates, but the trucks did not have sufficient traction. For each pair of undercutting plates, the winch trucks had to be assisted with a 10.9-Mg (12-ton) hand, hydraulic jack on each side of the tanks. Each plate had to be jacked about half the 2-m (6.56-ft) distance before the towing trucks had sufficient traction to pull them.

After the plates were removed, the monolith tanks settled onto the lower tanks and only minor horizontal alignment was needed. This alignment was done by welding a jacking jig to the inner wall and pulling it even with the outer wall before welding. Because of minor bulges in the walls of the upper tank, the lower wall generally needed to be pulled out for alignment.

The combined soil tanks were equipped with suction and gravity drainage systems and ports for inserting soil salinity sensors. Eight 25-mm (1-in.) × 1220-mm (48-in.) sintered stainless steel porous tubes with a bubbling pressure of 10 kPa (1.45 lb/in.^{2}) were placed in repacked soil in both the inner in outer halves of the bank bottoms. In addition, three, 102-mm (4-in.) diameter gravity drainage pipes packed in mortar sand were installed parallel to each 2-m (6.56-ft) wall. Five rows of four, 102-mm (4-in.) threaded, steel, female pipe flanges were welded to one end of each completed soil tank for future positioning of soil salinity sensors (fig. 6).

See Figure 6 at end of document

Figure 6–A monolith tank being lifted with a crane and positioned over a repacked soil tank.

Discussion

The monolithic and repacked soil tanks were satisfactorily completed and several aspects of the procedure merit emphasis.

1. In collecting the monoliths, the use of the lowering frames allowed precise control of the weighted down tanks and safe use of water tanks as deadweights.
2. The pipe columns and reinforcing angles allowed us to maintain straight 4-m (13.2-ft) long walls as the monolith tanks were pressed down.
3. The electric powered hydraulic jacks allowed us to undercut the monoliths in a few hours; whereas, other researchers have timed this operation in days or weeks.
4. To our knowledge, these are the largest reported soil monoliths transported a long distance for placement in a lysimeter.
5. Finally, collecting the monoliths, repacking the lower tanks, and joining the tanks were all accomplished in a timely manner without large amounts of hand labor.

Our decision to use heavy machinery and power equipment whenever possible resulted in timely collection of the monoliths, repacking of the lower soil tanks and joining of the tanks. After the lowering frames were installed, we pressed down and undercut the monoliths with five workers and a crane/backhoe operator in 5.5 days. Loading, hauling and unloading the two monoliths required 1.5 d. Positioning the two soil tanks for welding required three workers plus the crane and two winch truck operators about 7 h, but most of this time was required to hand jack the undercutting plates.

Our experience suggests some modifications in the equipment or procedures we used. When we undercut the first monolith, the cutting edge of the second undercutting plate could not be pulled up to meet the first plate. Instead the entire tank slid over the first plate, and about three hours were required to butt the two plates together and center the monolith over the two undercutting plates. After jacking the first plate under the second monolith, we chained it to the monolith tank. With the tank and plate rigidly attached, the second plate could be jacked in until the cutting edges of the two plates met. Some of our equipment such as the jacking beam and adjustable bar were too heavy to be easily moved by hand. Using lighter or readily bolted-together sections would be an improvement. Joining of the two tanks could have been made much easier if we had placed struts such as 150 or 200-mm (6 or 8-in.) standard pipe between the winch trucks and the soil tanks. The struts would have prevented the winch trucks from skidding and eliminated several hours of hand jacking to remove the undercutting plates.

References

Gee, G. W. 1987. Recharge at the Hanford site: Status report. PNL-6403. Richland, Wash.: Pacific Northwest Laboratory.

Gee, G. W., M. D. Campbell and S. O. Link. 1991. Arid site water balance using monolith lysimeters. In *Proc. of ASCE International Symposium on Lysimetry*, 219-227, 23- 25 July, Honolulu, HI. New York, N.Y.: Amer. Soc. of Civil Engineers.

Kirkham, R. R., G. W. Gee and T. L. Jones. 1984. Weighing lysimeters for long-term water balance investigations at remote sites. *Soil Sci. Soc. Am. J.* 48(5):1203-1205.

Marek, T. H., A. D. Schneider, T. A. Howell and L. L. Ebeling 1988. Design and construction of large weighing monolithic lysimeters. *Transactions of the ASAE* 31(2):477-484.

Mukammal, E. E., G. A. McKay and V. R. Turner. 1971. Mechanical balance — Electrical readout weighing lysimeter. *Boundary Layer Meteorology* 2(2):207-217.

San Joaquin Valley Drainage Program. 1990. In *A Management Plan for Agricultural Subsurface Drainage and Related Problems on the Westside San Joaquin Valley*. U.S. Dept. of Interior and California Resources Agency. Sacramento, Calif.: California Dept. of Water Resources.

Schneider, A. D., T. H. Marek, L. L. Ebeling, T. A. Howell and J. L. Steiner. 1988. Hydraulic pulldown procedure for collecting large soil monoliths. *Transactions of the ASAE* 31(4):1092-1097.

Schneider, A. D. and T. A. Howell, 1991. Large, monolithic, weighing lysimeters. In *Proc. of ASCE International Symposium on Lysimetry*, 37-45, Honolulu, HI, 23-25 July, New York, N.Y.: Amer. Soc. of Civil Engineers.

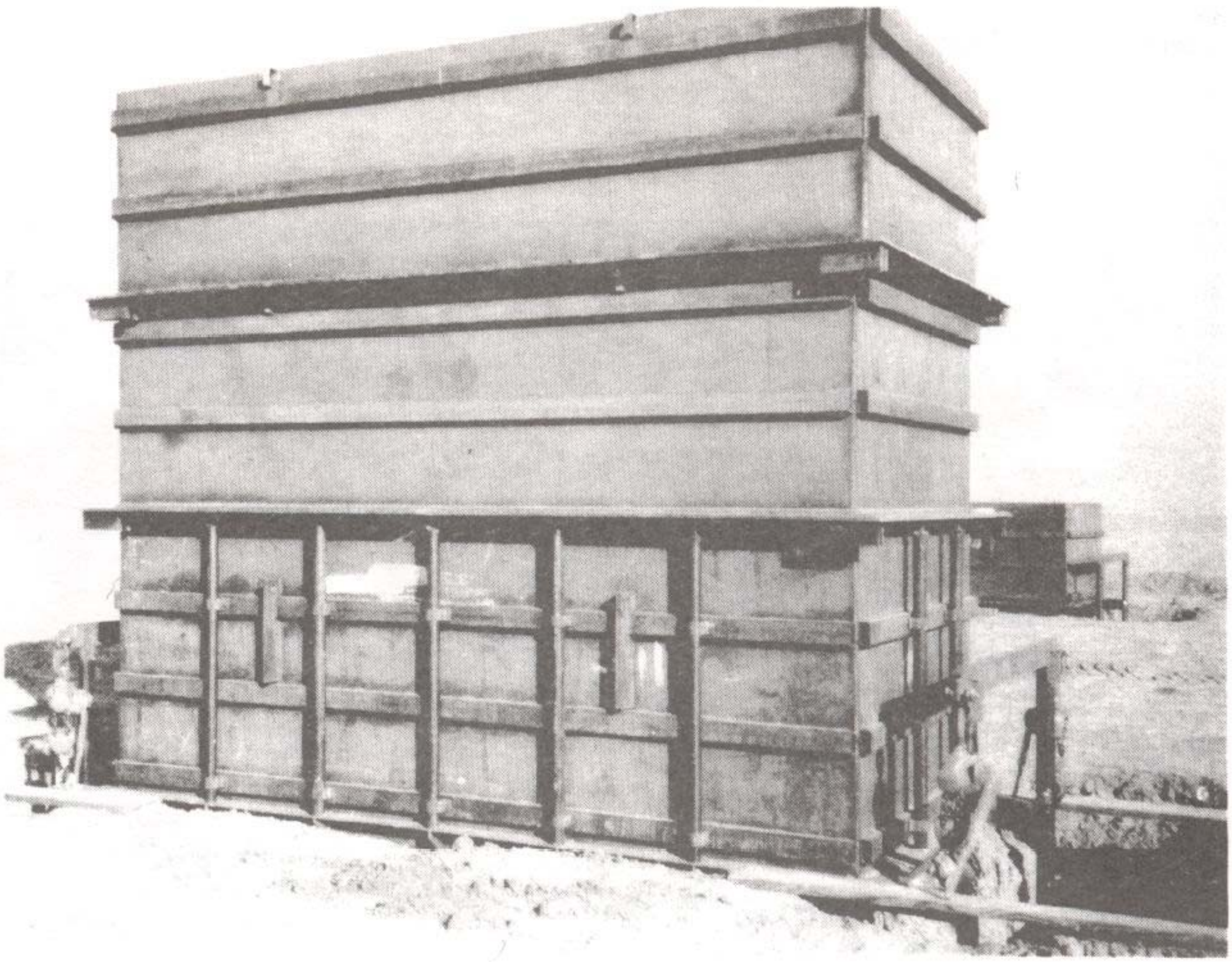

Figure 3 - Monolith tank with all equipment and deadweights in place and pressed down about 0.3 m.

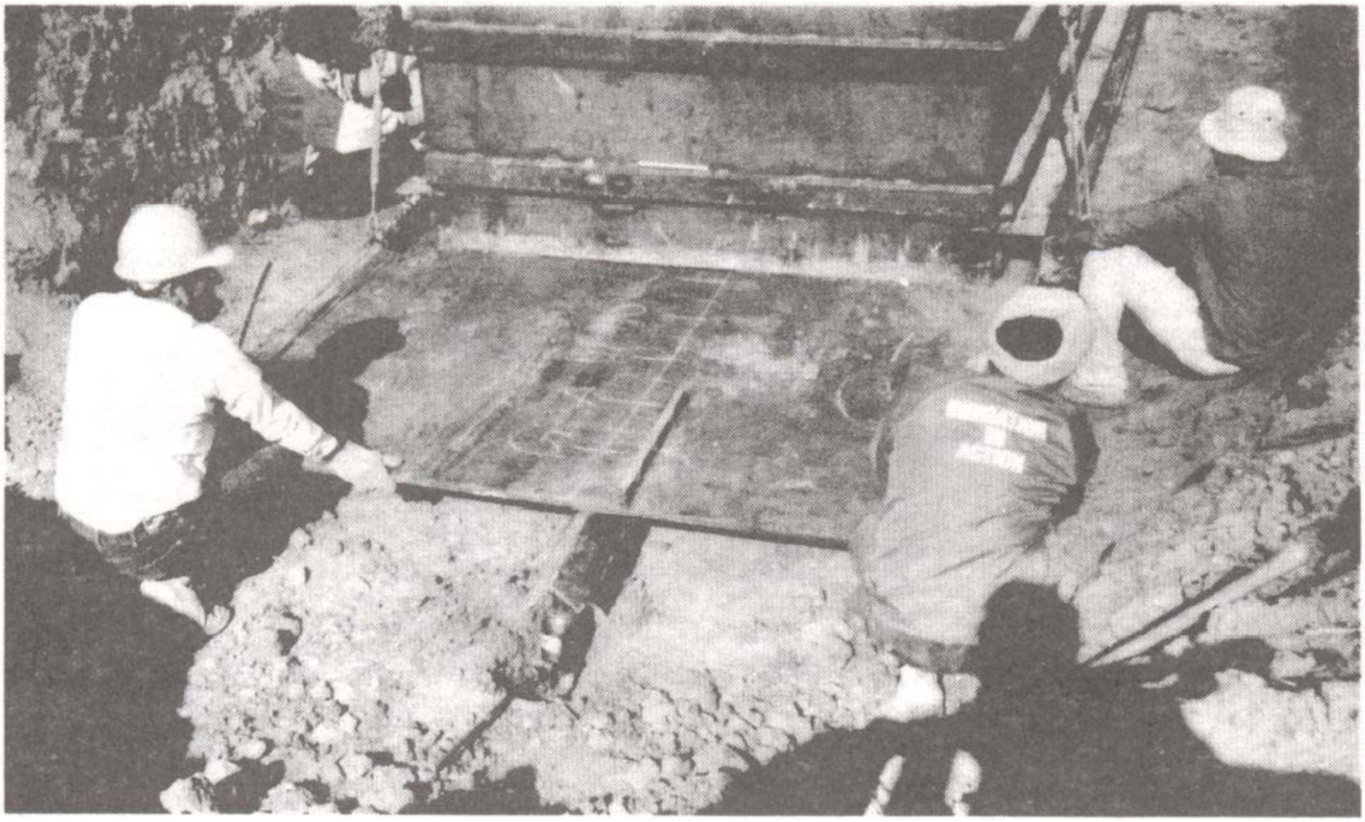

Figure 4 - An undercutting plate being jacked under one of the soil monoliths.

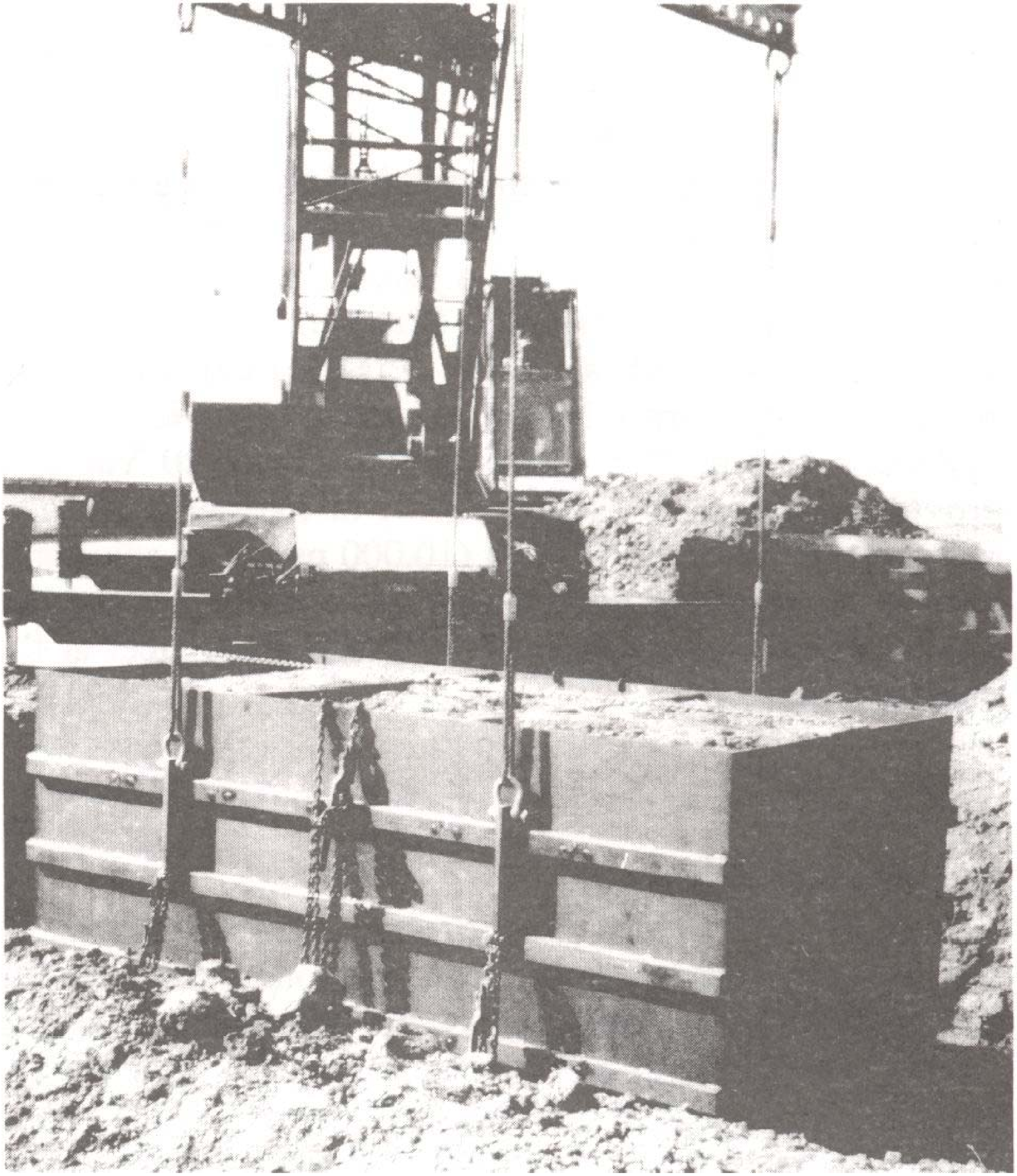

Figure 5 - A soil monolith being lifted from the ground to be loaded onto a truck.

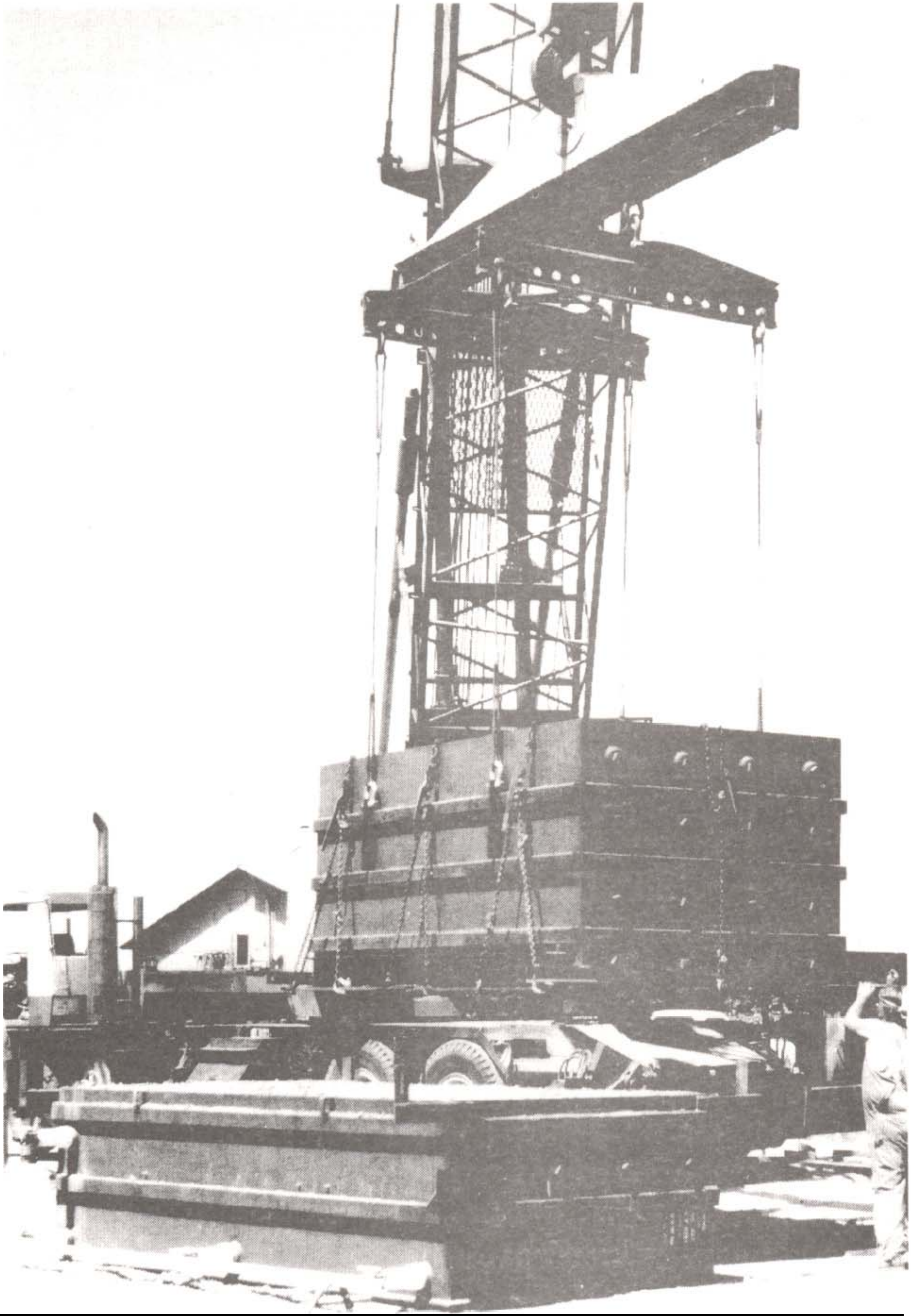

Figure 6 - A monolith tank being lifted with a crane and positioned over a repacked soil tank.